Chapter 2
Extraction/Monitoring Wells (Vertical/Horizontal Wells) and Soil Flushing

2-1. General

In the chapter's first section, extraction/monitoring well components and how they function, along with well development techniques, are briefly described. Soil flushing methods are also discussed. The second portion of the chapter is a hazard analysis with controls and control points listed.

2-2. Technology Description

a. Extraction/Monitoring Well Components and Methods.

Extraction/monitoring wells are typically vertical or horizontal PVC, steel, or stainless steel pipes with screened sections to allow groundwater or soil gas to enter the pipe interior. The wells are typically installed into a vadose (unsaturated) zone or an aquifer at strategic locations to extract or monitor groundwater or soil gas. The pipe is installed into a slightly oversized borehole, typically created by using a hollow stem auger-drilling rig. Air and mud rotary methods may be used to install deeper wells. The annular space between pipe and boreholes, where the pipe is screened, is typically surrounded with porous sand or other packing to filter out larger particles as water/air enters the well. The boring outside the well pipe, above the filter pack (above the screened well section), is typically sealed with cement or bentonite slurry to prevent mixing of groundwater/air from above the screened zone with water or air entering the well down the boring and above the filter pack.

A down-hole pump (electrical or air driven) is typically used for water extraction wells to move the contaminated water to the surface. A surface vacuum pump (positive displacement, centrifugal, or regenerative depending on air flow, soil formations, and other factors) is used for air extraction. Water is usually extracted from monitoring wells using manual bailers, peristaltic, or similar pumps that may or may not be dedicated to each well.

Small "alpha" type air pumps feeding tedlar bags are typically used for air monitoring wells to extract samples through a well cap nipple, or through a small tube inserted through the well cap and down the barrel of the well. The extracted water/air may then be analyzed (monitoring wells) or treated (extraction wells) with above-ground treatment technologies. A schematic of a typical vertical extraction/monitoring well is presented in Figure 2-1. Once installed, the wells are developed by surging water along the well, jetting, pumping, bailing or air sparging (on and off) to remove drilling mud, silt, and cutting materials. The procedure allows free flowing water/air into the well.

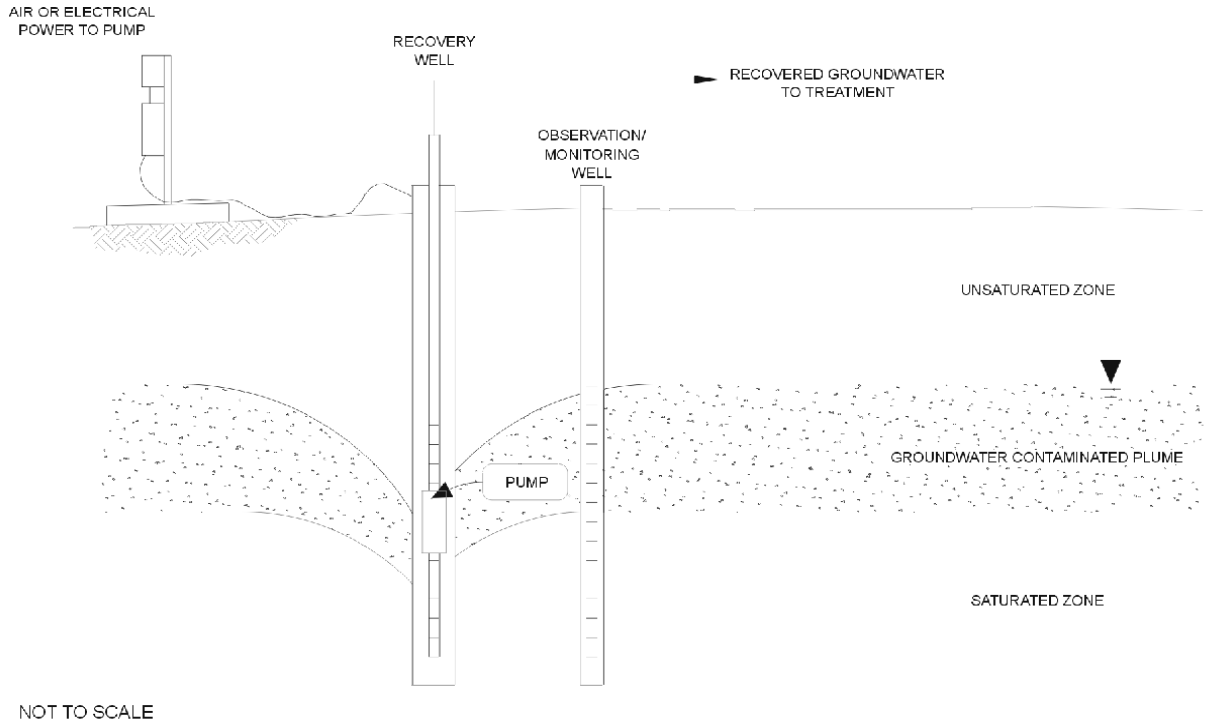

FIGURE 2-1. VERTICAL EXTRACTION WELL

An alternative to vertical extraction wells is horizontal extraction of water/air through wells installed using either a drill rig designed to slant or curve the boring or temporary trenches to install the well pipe at a horizontal orientation. Horizontal wells offer a greatly enhanced capture zone as a long horizontal length of the well can be screened and filter packed, while vertical wells' screened lengths are limited by the depth of the aquifer. Figure 2-2 shows a schematic of a horizontal well.

Extraction wells are the most common water/air recovery technology used for groundwater/soil cleanup in "pump-and-treat" systems and in soil vapor extraction (SVE) systems. The effectiveness of pump-and-treat systems, and hence extraction wells, depends strongly on hydrogeologic properties (e.g., porosity, permeability) and contaminant properties (e.g., volatility, partitioning coefficients).

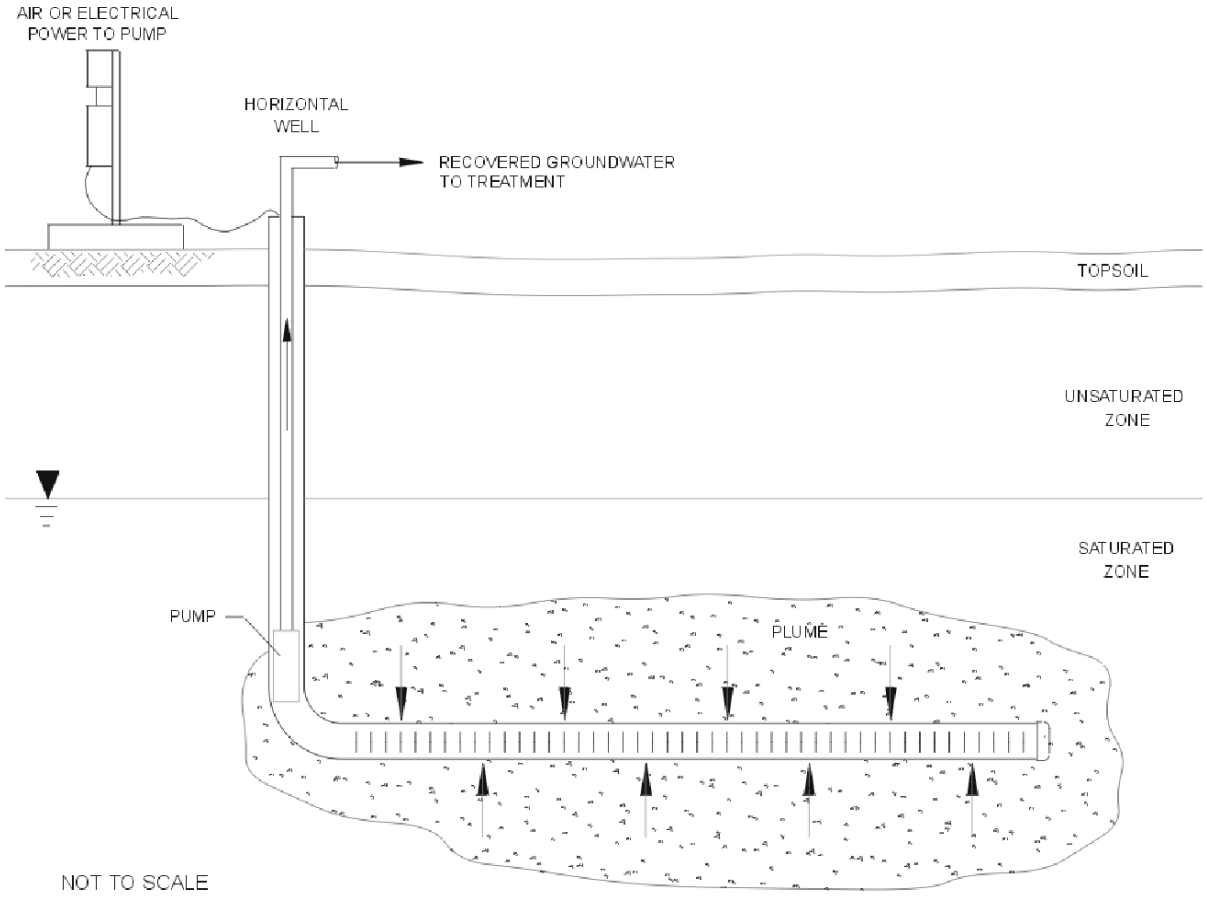

FIGURE 2-2. HORIZONTAL EXTRACTION WELL

b. Well Development Techniques.

When the performance of wells declines, they are often cleaned and redeveloped using some of the well development processes discussed below under Soil Flushing Methods, but they may also be rehabilitated via additional processes. The additional processes may include:

- Acidification (e.g., hydrofluoric, sulfamic, or hydrochloric acids) to chemically react with and remove acid-soluble scales and hydrolyze biofouling.
- Hypochlorite or peroxidation to kill and hydrolyze biofouling.
- Mechanical scrubbing or swabbing to clean scale and biofouling.

Wells may also be redeveloped using standard development techniques, such as surging, to remove accumulated fines and sediments and rejuvenate well performance.

c. Soil Flushing Methods.

Soil flushing is a technology also linked to pump-and-treat methods (Figure 2-3). Water, with or without additives (such as surfactants) to enhance the removal of contaminants, is pumped through or infiltrated through contaminated soils to flush (in-situ wash) contaminants into the groundwater for collection by groundwater extraction wells and treatment. If enhancers are added, typical additives are surfactants that act as detergents, change interfacial tensions between the soil/water/contaminants, and form micelles, thus enclosing contaminants and enhancing the rate of contaminant removal and recovery. To flush material from soils into the groundwater requires that groundwater be captured, extracted and treated, or that the groundwater be treated in-situ to prevent further spread of contamination. Soil flushing is a remediation enhancement that is infrequently employed.

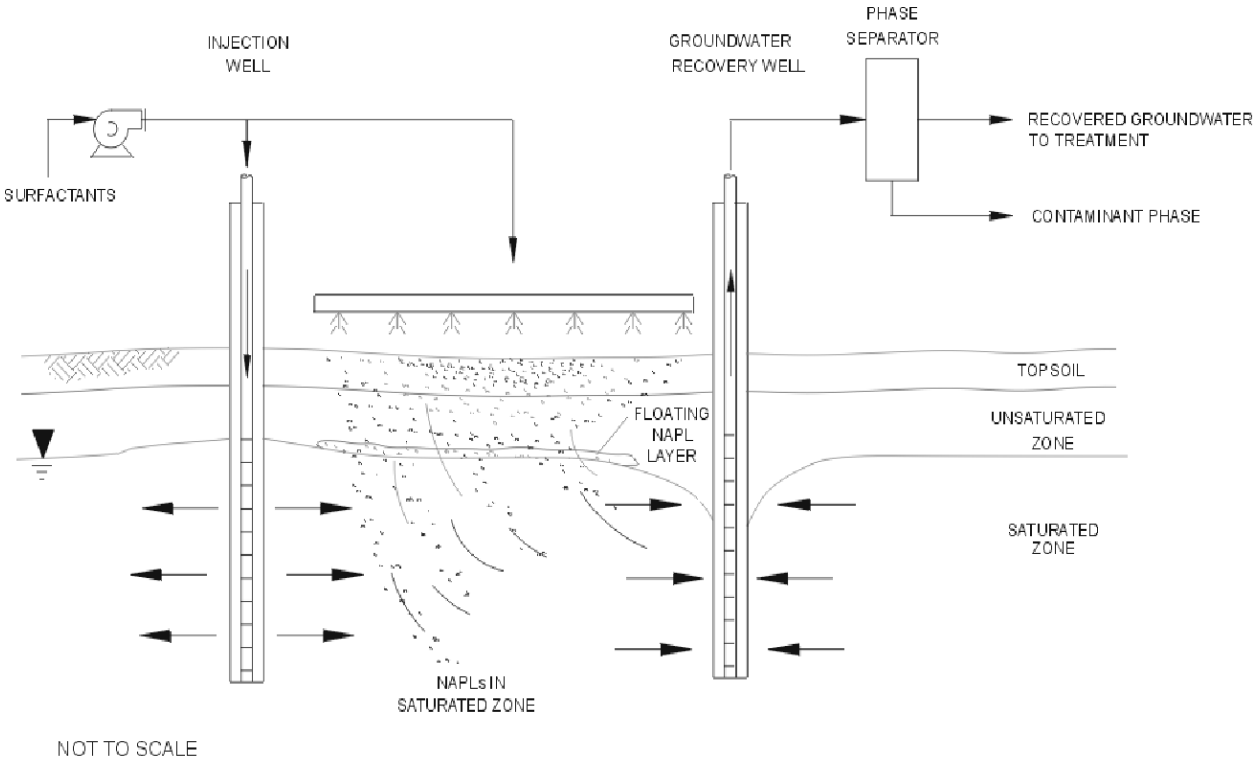

FIGURE 2-3. SOIL FLUSHING

2-3. Hazard Analysis

Principal unique hazards associated with extraction/monitoring wells (vertical/horizontal wells) and soil flushing, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Equipment Hazards.*
Description. During drilling operations, heavy equipment, such as augers, cables, buckets, and pipes, is periodically raised overhead and placed into or above the well. Thus, workers may be exposed to swinging equipment during lifting, or may be exposed to crushing hazards if equipment falls or is carelessly lowered. Loose clothing may become entangled in cables used to raise and lower equipment or on the equipment itself. Lowered augers, buckets, or direct push drilling methods (using hydraulic pressure to advance a soil boring) may further pose a crushing hazard to hands or feet. Rough edges or spaces on cables, auger flights, buckets, and pipe may cause cuts and abrasions.

Control. Controls for equipment hazards include:
- Establish a work zone around the drilling rig and permit only those personnel and equipment required for the task within the zone.
- Inspect lifting equipment regularly and operate it safely.
- Raise equipment only as high as needed.
- Maintain contact with the raised equipment to help minimize swinging.
- Wear appropriate clothing and equipment (site workers). (Avoid wearing loose clothing.)
- Avoid contact with auger edges, running cables, and pipe; wear work gloves to prevent cuts and abrasions from exposed spurs, wires, and edges. No jewelry should be worn (operators).
- Train workers in the equipment and operational hazards associated with drilling operations, including safety features built into the equipment.

CONTROL POINT: Construction, Maintenance

(2) *Rotating Equipment.*
Description. The rotating auger and other rotating or moving parts, such as "cat heads" and winches, pose a potential hazard to workers if loose clothing becomes entangled with the revolving equipment.

Control. Controls for rotating equipment include:
- Secure all loose clothing and remove jewelry.
- Use low-profile auger pins and long-handled shovels to remove soil cuttings from the borehole.
- Use cable systems with caution and inspect regularly for loose strands or frayed wires that may become entangled in loose clothing.
- Use drilling equipment equipped with a cut-off switch accessible to all drill crew members.
- Train operators on safe drilling practices, including hazard recognition in moving parts, entanglement, and pinch points of equipment.

CONTROL POINT: Construction, Maintenance

(3) *Utility Contact Hazards*.

Description. Fire, explosion, or electrocution hazards may exist when using hollow-stemmed auger, direct push, or other drilling methods if the drilling mast or auger comes in contact with overhead electric lines, or ruptures underground utilities or tank/piping systems.

Control. Controls for utility contact hazards include:

- Train the operators in the hazards of drilling in the vicinity of underground or overhead utilities.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures for electrocutions, burns, and extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency drill isolation procedures.
- Identify the location of all below- and above-ground utilities prior to drilling by contacting local utilities and public works personnel.
- Use a metal detector to help detect buried metal piping. When there is any doubt or uncertainty, probe with a metal rod prior to excavation or hand excavate to determine the exact location of utilities prior to drilling. Once utilities are located, careful excavation by backhoe may be allowed.
- Have an observer to the side to guide when raising a drill mast.
- Operate the mast at its lowest height; different drill rigs will have different mast elevations and may be operated at different heights.
- Do not move the drilling rig with the mast raised.
- Locate overhead hazards and design so that installations using erect equipment are not necessary in that area, if possible.

CONTROL POINT: Design, Construction

(4) *Flammable or Combustible Material*.

Description. Soil boring using hollow-stemmed augers or other drilling methods may cause a fire or explosion in soils saturated with flammable or combustible materials under unusual or extraordinary conditions. Sparks generated when an auger contacts rocks, metal, or other underground objects may ignite a flammable atmosphere inside the borehole. Examples of materials particularly subject to ignition in this manner are carbon disulfide (CS_2), methane, natural gas, ethane, propane, ethylene, benzene, or hydrogen sulfide, a decomposition product.

Control. Controls for flammable/combustible materials include:

- Use methods such as mud or water rotary drilling in areas suspected to contain soils saturated with flammable or combustible materials. These methods add moisture to the cutting area unlike hollow-stem augers.

CONTROL POINT: Design, Construction

(5) *Electrical Fires or Explosions.*
Description. Electricity in a wet environment and in the presence of flammable, floating layers of explosive NAPL may cause a fire or explosion.

Control. Controls for electrical fires include:
- Verify that the hazardous area classifications, as defined in NFPA 70 Chapter 5, sections 500.1 through 500.10, are indicated on the drawings.
- Verify that all controls, wiring, and equipment conforms to the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Perform all electrical work according to code and under the supervision of a state licensed master electrician.
- Use equipment that is grounded or provided with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70 requirements.
- Permit only trained, experienced, and authorized workers to work on the systems.
- Include appropriate lockout/tag-out equipment and procedures in the construction and O&M of the system.
- Have fire extinguishers rated for energized electrical systems readily available where electrical equipment is installed and operated

CONTROL POINT: Design, Construction, Operations, Maintenance

(6) *Extraction of Flammable Liquids.*
Description. Extraction of flammable liquids may cause a fire if the material is ignited via extraction, transfer, or storage, or if gases vented from the storage tank come in contact with a spark or other source of ignition. Fires may also occur if extraction pumps are not selected and installed in accordance with the appropriate EM 385-1-1, Section 11, and NFPA 70 requirements.

Control. Controls for extraction of flammable liquids include:
- Use equipment that is grounded or provided with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70 requirements.
- Direct tank vents to prevent contact with sources of ignition.
- Verify that the hazardous area classifications, as defined in NFPA 70 Chapter 5, 500.1 through 500.10, are indicated on the drawings.
- Verify that all controls, wiring, and equipment, including the piping system, conforms to the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Permit only trained, experienced, and authorized workers to work on the systems.
- Include appropriate lockout/tag-out equipment and procedures in the construction and O&M of the system.

- Have fire extinguishers rated for energized electrical systems readily available where electrical equipment is installed and operated.

CONTROL POINT: Design, Construction, Operations, Maintenance

(7) *Steam Pressure Washing*.
Description. Steam pressure washing of equipment may expose workers to thermal, burn or injection hazards, eye hazards from flying projectiles dislodged during washing, slip hazards from wet surfaces, and noise hazards.

Control. Controls for steam pressure washing include:
- Use insulated gloves (e.g., silica fabric gloves) to prevent thermal burns and keep all body parts away from the ejecting point of the steam pressure nozzle.
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.
- Equip with deadman or kill switch if not provided.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.
- Allow only trained and authorized workers to operate the steam pressure equipment.

CONTROL POINT: Construction, Operations, Maintenance

(8) *Drill Rigs*.
Description. Drill rigs can seriously injure workers during positioning for drilling.

Control. Controls for drill rigs include:
- Equip drill rigs and other vehicles with a backup alarm that alerts workers to moving vehicles.
- Drill rigs shall be leveled and stabilized. Appropriate blocking must be used when soil conditions dictate.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Allow only trained and authorized workers familiar with drilling operation hazards to work near the equipment.

CONTROL POINT: Construction, Maintenance

(9) *UV Radiation*.
Description. During site activities, workers may be exposed to direct and indirect sunlight and corresponding UV radiation. Even short-term exposure to sunlight can cause burns and other dermal damage. Exposure to hot and humid conditions may also result in heat stress, which can manifest itself as heat exhaustion and heat stroke.

Control. Controls for UV radiation include:

- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen. Loose clothing and sun hats should not be worn around moving parts that may snag the worker and draw him or her into a danger zone. All UV skin barrier creams should be pre-approved. Some creams contain zinc and other constituents that can cause false readings in analytical samples.
- Shade work and break areas if possible.
- Minimize exposure to heat stress by taking frequent breaks, drinking adequate fluids, and performing work during the early morning and late afternoon hours.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Construction, Operations

(10) *Muscle Injuries*.
Description. Manual lifting of heavy objects may expose workers to back, arm, and shoulder injuries.

Control. Controls for muscle strain include:

- Use mechanical lifting equipment to lift heavy loads.
- Use proper lifting techniques including stretching, bending at the knees, and bringing the load close to the body prior to lifting (see EM 385 1-1, Section 14). Use two people if necessary for manual lifting.

CONTROL POINT: Design, Construction, Operations, Maintenance

(11) *Emergency Wash Equipment*.
Description. Emergency shower/eye wash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards and walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping and electrical hazards.

(12) *Design Field Activities.*
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:
- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Contamination Hazards.*
Description. Exposure to airborne dusts, VOCs, and metals in contaminated soils or groundwater brought to the surface during drilling, soil and groundwater sampling, and infiltration system installation can be hazardous to on-site personnel. During well installation, site workers may be exposed to gasoline, diesel fuel, or other organic materials, as well as heavy metals such as lead and chromium. These hazards can be contacted through dermal exposure, ingestion, or vapor inhalation. Workers may also be exposed to reactive, caustic, or acidic materials from cuttings and groundwater.

Control. Controls for chemical contamination hazards include:
- Use personal protective equipment (PPE) selected by a qualified health and safety professional (e.g., air-purifying respirators, chemically resistant disposable coveralls, water/chemical impervious gloves [e.g., nitrile], and rubber or steel-toed leather boots).
- Have frequent health and safety meetings.
- Use experienced workers, decontamination stations, or other standard procedures.
- Test soils for reactive, highly flammable, or corrosive materials.
- Design all installation methods appropriately.
- Use non-sparking tools and intrinsically safe equipment in extreme conditions (e.g., carbon disulfide, CS_2) if emissions are expected to be high.
- Conduct personnel and general area monitoring for airborne chemicals when exposures may potentially exceed half of the threshold limit value (TLV) or permissible exposure limit (PEL). Also conduct area monitoring when airborne combustible chemical concentrations exceed 1/10 of the lower explosive limit (LEL).
- Use proper respiratory protection (e.g., air-purifying respirator with filters or organic vapor cartridge, or both) if ventilation or other engineering, work

practice, or administrative controls are insufficient to maintain exposures less than the TLV or PEL.

- Select respiratory protective equipment in accordance with the OSHA regulation 29 CFR 1910.134 and the National Institute for Occupational Safety and Health (NIOSH) guidelines.

CONTROL POINT: Construction, Maintenance

(2) *Additive Hazards*.

Description. Additives (usually surfactants used in flushing) enhance exposure to contaminants by increasing dermal absorption and holding contaminants on skin. For example, linear alkyl benzene sulfonate or ethoxylate surfactants could be used to enhance recovery of contaminants as part of a pump-and-treat groundwater extraction program. This could also enhance concentrations of contaminants in the recovered water, increasing the risk and hazard of contact with that water. In addition, additives can increase the solubility of contaminants, raising concentrations to which personnel are exposed.

Control. Controls for additive hazards includes:

- Select additives (system designer) with the lowest health and safety impact that can still do the job (e.g., avoid use of materials such as dimethyl sulfoxide (DMSO) which enhances dermal absorption, when other solvents are available and practical).
- Allow only trained and authorized workers to handle the chemicals and equipment.

CONTROL POINT: Design, Operations

(3) *Chemical Fire or Explosion*.

Description. Fire or explosion or chemical release hazards (inhalation/ingestion/asphyxiation) may exist when using hollow-stem auger, direct push, or other drilling methods if drilling ruptures underground utilities or tanks/overhead piping systems that contain hazardous chemicals.

Control. Controls for chemical fire or explosion include:

- Perform a utility survey, probe with a metal rod prior to excavation, or hand excavate to determine the exact location of underground lines prior to drilling.
- Develop actions/procedures to locate overhead hazards during design.
- Allow only trained, experienced, and authorized workers near and on the drilling operation.

CONTROL POINT: Construction

(4) *Acids*.

Description. Acids used in well flushing or rehabilitation may pose skin, eye, or inhalation hazards upon contact.

Control. Controls for acids include

- Use closed acid injection systems to minimize worker exposure to acids.
- Wear PPE, such as neoprene gloves, chemically resistant coveralls, safety goggles, and a face shield.
- Allow only trained and authorized workers to handle and work in areas with acids and bases.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

(1) *Equipment.*
Description. Use of a neutron or gamma source in down-hole logging systems to log wells may pose a radiation hazard if improperly used or if damaged in such a way as to expose the sources.

Control. Controls for equipment hazards include:
- Use personnel with the proper training and experience in the use of neutron density gauges and proper maintenance of the instrument.
- Comply with the Nuclear Regulatory Commission (NRC) Standards for Protection Against Radiation (10 CFR 20), NRC Rules of General Applicability to Domestic Licensing of Byproduct Material (10 CFR 30).
- Note the license type required for the particular source (10 CFR 31, 32, or 39) as well as license conditions and OSHA 1910.1096 or 29 CFR 1926.53 criteria.

CONTROL POINT: Design, Construction, Maintenance

(2) *Contaminants.*
Description. Contaminants in the groundwater and soil may pose a rare radiation hazard to personnel through inhalation or ingestion of radioactive materials during installation, sampling, and maintenance of wells or well-related systems. Buildup of radioactive scale in the well and associated piping may present an external exposure hazard. Contaminants may include naturally occurring radioactive material (NORM), radium, thorium, and uranium, or radioactive wastes that have been buried in previous disposal activities.

Control. Controls for radioactive contaminants include:
- Test the soil and groundwater to determine if elevated levels of radioactive materials are present.
- Consult a qualified health physicist if elevated levels occur to determine the exposure potential and any necessary engineered controls or PPE.

CONTROL POINT: Design, Construction, Maintenance

d. Biological Hazards.

(1) *Biological Contaminants.*
Description. At those sites involving medical wastes or sewage sludge, microorganisms in the groundwater and soil may cause exposure hazards during the installation, sampling, and maintenance of the wells or well-related systems. Workers may be exposed to inhalation/ingestion or dermal contact with pathogens, such as *Coccidioides sp.*, *Histoplasma sp.*, and *Mycobacterium sp.* The resulting exposure may result in an occupational illness.

Control. Controls for biological contaminants include:

- Test microorganisms in the groundwater and soil and determine the appropriate PPE to prevent exposure. The appropriate PPE typically includes an air-purifying respirator equipped with N, R, or P100 or N, R or P95 particulate air filters approved for microbial inhalation hazards.
- Enforce (strictly) eating, drinking, and smoking restrictions prior to washing/decontamination. Decontamination with water and or disinfectant soaps may be used to control exposure.
- Wear chemically resistant protective overalls to prevent clothes from becoming grossly contaminated with wastes, soils, or contaminated water. If contaminated clothing is laundered, use a commercial laundry familiar with cleaning procedures for industrial clothing. These procedures include employee hazard warnings and cleaning solution disposal requirements.

CONTROL POINT: Design, Construction

(2) *Dangerous Insects or Animals.*

Description. Well vaults or enclosures may have snakes, spiders, scorpions or other potentially dangerous insects and animals sheltering or trapped in them that could bite or sting workers during operations or maintenance. Other biological hazards include bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus. Mosquitoes can transmit the West Nile Virus.

Control. Controls for dangerous insects or animals include:

- Design well vaults with tight covers where practical to prevent entry of insects and animals.
- Remove well vault covers with a hook or other tools to prevent possible bites or stings.
- Inspect vaults after opening and prior to entry to determine if snakes, spiders, scorpions, or other potentially dangerous insects and animals are present. If present, the animals should be removed in a safe manner by a qualified health and safety professional.
- Perform periodic inspections of the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies for removal.
- Use tick and insect repellents containing N,N-diethyl-m-toluamide (DEET) 25% as the active ingredient for exposure control. Clothing may be treated with permethrin clothing repellent BEFORE donning, for added protection. Workers should check their skin and clothing for ticks periodically throughout the workday.

CONTROL POINT: Design, Operations, Maintenance

(3) *Pests*.

Description. Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus. Mosquitoes can transmit West Nile Virus.

Control. Controls for pests include:

- Periodically inspect the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies for removal.
- Use tick and insect repellents containing N,N-diethyl-m-toluamide (DEET) 25% as the active ingredient for exposure control. Clothing may be treated with permethrin clothing repellent BEFORE donning, for added protection. Workers should check their skin and clothing periodically throughout the work day.

CONTROL POINT: Construction, Operations, Maintenance